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(71) Applicant

Merrall Teroude et

Compagnie

(France)

16 rue d'Antony

67064 Strasbourg

France

(72) Inventors

Wolfgang Fricken

Eckhart Gerhart

(74) Agent and/or Address for

Service

W H Book Greener & Co

7 Stom Building

Lincoln's Inn

London WC2A 3BZ

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(54) Process for preparing 4-amino-5-hexenoic acid

(57) 4-Amino-5-hexenoic acid is prepared by:

(a) reacting 5-oxo-2-pyrrolidine-acetonitrile with hydrogen and dimethylamine in the presence of a palladium catalyst to form N,N-dimethyl-2-[5'-oxo-2'-pyrrolidine]ethylamine;

(b) oxidizing N,N-dimethyl-2-[5'-oxo-2'-pyrrolidine]ethylamine to produce the corresponding N-oxide derivative;

(c) pyrolysis of the N-oxide derivative to form 5-vinyl-2-pyrrolidinone;

(d) optionally, separating N,N-dimethyl-2-[5'-oxo-2'-pyrrolidine]ethylamine by-product from the 5-vinyl-2-pyrrolidinone product; and

(e) hydrolyzing 5-vinyl-2-pyrrolidinone to form 4-amino-5-hexenoic acid.

The products of (a) and (b) are

claimed per se.

MFC.
PRODN OF 5-VINYL-2-PYRROLIDINONE
INTERMEDIATE + FOR 4-AMINO-5-
HEXENOIC ACID, USEFUL AS IRREVERSIBLE
INHIBITOR OF GAMMA-AMINO BUTYRIC
ACID TRANSAMINASE FOR TREATING
TARDIVE DYSKINESIA.

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SPECIFICATION

Process for preparing 4-amino-5-hexenoic acid

- 5 The present invention is directed to a novel process for preparing 4-amino-5-hexenoic acid and to novel intermediates employed in the process. 5
 4-Amino-5-hexenoic acid (also known as 4-vinyl-4-aminobutyric acid, γ -vinyl- γ -aminobutyric acid, or "vinyl-GABA") is described in U.S. Patent 3,960,927. 4-Amino-5-hexenoic acid is an irreversible inhibitor of γ -aminobutyric acid transaminase (GABA-T) and is, therefore, capable of 10
 10 increasing the level of γ -aminobutyric acid (GABA) in the CNS. The compound is useful for treating disorders associated with depletion of GABA levels in the CNS, for example, tardive dyskinesia, schizophrenia, and seizure disorders such as epilepsy. The biochemical and pharmacological effects of 4-amino-5-hexenoic acid are described in Lippert et al., *Eur. J. Biochem.*, 74, 441 (1977), Metcalf, *Biochemical Pharmacology*, 28, 1705 (1979), Lippert et al., *Brain Research Bulletin*, 5, 375 (1980), and Palfreyman et al., *Biochemical Pharmacology*, 30, 817 (1981). 15

U.S. Patents 4,178,463, 4,235,778, and 4,254,204 disclose the preparation of 4-amino-5-hexenoic acid by reacting a suitable derivative of 2-vinylcyclopropane-1,1-dicarboxylic acid with ammonia to form a 3-[carboxy-, carboxamido-, or tert-butoxycarbonyl]-5-vinyl-2-pyrrolidinone 20 and treating the 3-[carboxy-, carboxamido-, or tert-butoxycarbonyl]-5-vinyl-2-pyrrolidinone with a strong acid. The patents also describe the decarboxylation of a 3-[carboxy-, carboxamido-, or tert-butoxycarbonyl]-5-vinyl-2-pyrrolidinone to afford 5-vinyl-2-pyrrolidinone which can then be converted via bromination and dehydrobromination to 5-ethyl-2-pyrrolidinone which can be hydrolyzed to 4-aminohex-5-yneic acid. 4-Aminohex-5-yneic acid is described in U.S. Patent No. 25 3,959,356.

In a first process aspect, the present invention provides a process for preparing 5-vinyl-2-pyrrolidinone which comprises:
 (a) reacting 5-oxo-2-pyrrolidine-acetonitrile with hydrogen and dimethylamine in the presence of a palladium catalyst to form N,N-dimethyl-2-[5'-oxo-2'-pyrrolidine]ethylamine;
 30 (b) oxidizing N,N-dimethyl-2-[5'-oxo-2'-pyrrolidine]ethylamine with an oxidizing agent to produce the corresponding N-oxide derivative;
 (c) pyrolysis of the N-oxide derivative to form 5-vinyl-2-pyrrolidinone; and, optionally,
 (d) separating N,N-dimethyl-2-[5'-oxo-2'-pyrrolidine]ethylamine by-product from 5-vinyl-2-pyrrolidinone product.

35 In a second process aspect, the invention provides a process for preparing 4-amino-5-hexenoic acid which comprises preparing 5-vinyl-2-pyrrolidinone according to Steps (a), (b), (c), and (d) as described hereinabove and then hydrolyzing the 5-vinyl-2-pyrrolidinone product.

In a third process aspect, the invention provides a process for preparing 5-vinyl-2-pyrrolidinone which comprises the pyrolysis of the N-oxide of N,N-dimethyl-2-[5'-oxo-2'-pyrrolidine]ethylamine and, optionally, separating N,N-dimethyl-2-[5'-oxo-2'-pyrrolidine]ethylamine by-product 40 from the 5-vinyl-2-pyrrolidinone product.

In a fourth process aspect, the invention provides a process for preparing N,N-dimethyl-2-(5'-oxo-2'-pyrrolidinone)ethylamine, or the N-oxide thereof, which comprises reacting 5-oxo-2-pyrrolidineacetonitrile with hydrogen and dimethylamine in the presence of a palladium catalyst. 45 and, when the N-oxide is required, oxidizing the N,N-dimethyl-2-[5'-oxo-2'-pyrrolidinone]ethylamine product of acid reaction.

The preparation of N,N-dimethyl-2-[5'-oxo-2'-pyrrolidinone]ethylamine, the N-oxide thereof, 5-vinyl-2-pyrrolidinone, and 4-amino-5-hexenoic acid from 5-oxo-2-pyrrolidineacetonitrile is depicted schematically below in FIGURE 1:

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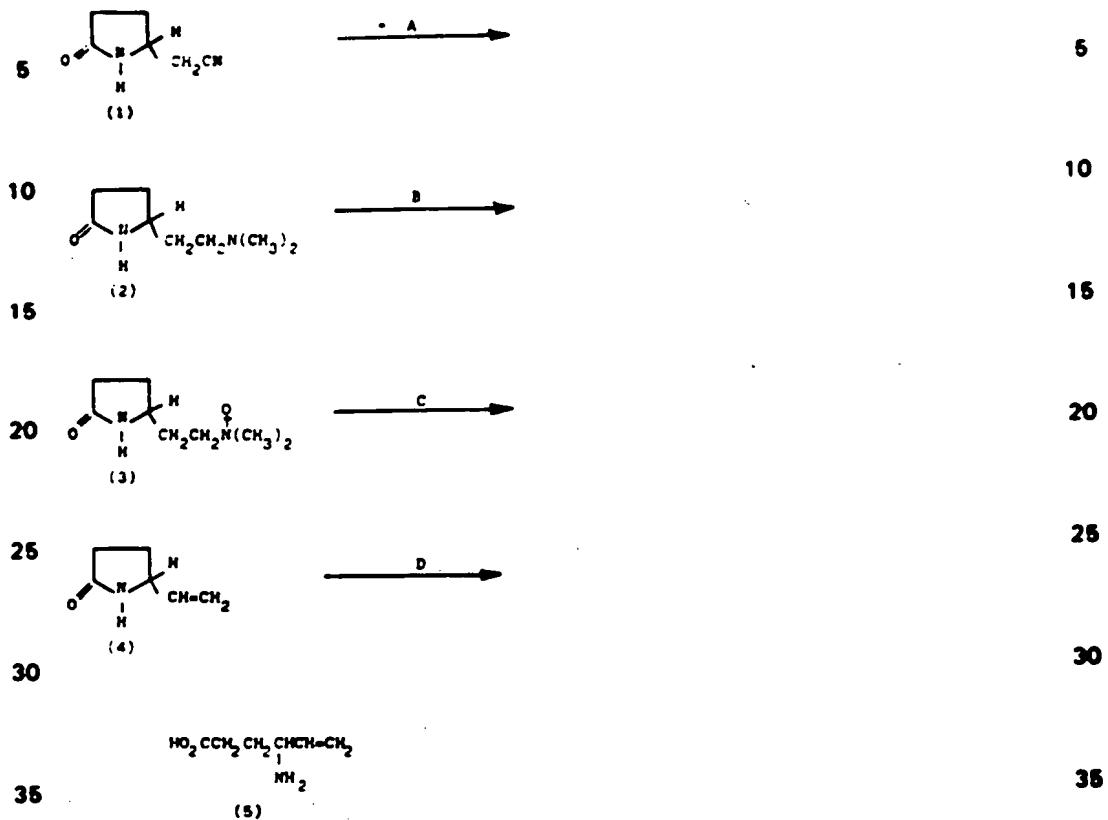
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PICURE 1



In Step A, 5-oxo-2-pyrrolidinonesecetonitrile (1) is reacted with hydrogen gas and dimethylamine in the presence of a palladium catalyst, such as palladium-on-barium sulfate or palladium-on-alumina oxide (Al_2O_3) to produce N,N-dimethyl-2-[5'-oxo-2'-pyrrolidine]ethyleamine (3). This reaction is analogous to that described by Kindler et al., Arch. Pharm., 283, 184 (1950). The reaction can be carried out in an inert solvent, preferably a (C_1 - C_4)alkanol or water, at a temperature from about 20 to 100°C. Ambient temperature is preferred. The hydrogen gas pressure can range from about one atmosphere to about 20 atmospheres. Two atmospheres are preferred. The reaction time will vary depending upon the temperature and pressure. The product of the reaction is recovered from the reaction mixture by conventional procedures. A preferred procedure involves filtering the reaction mixture to remove the catalyst, evaporating the solvent from the filtrate to give a residue, and distilling the residue under vacuum. This procedure will remove dimeric and trimeric by-products which interfere with the next step of the process.

50 process.

In Step B, N,N-dimethyl-2-(5'-oxo-2'-pyrrolidine)ethylamine (2) is oxidized in manner known per se to give the corresponding N-oxide derivative (3). The oxidizing agent employed in Step B can be any reagent known in the art to be useful for oxidizing a tertiary amine to the corresponding N-oxide derivative. Suitable reagents, conditions, and solvents for the oxidation 55 reaction will be apparent to those skilled in the art. A preferred reagent is hydrogen peroxide in water, for example, 30% hydrogen peroxide-water, or in a (C₁-C₆)alkanol, for example, methanol or ethanol, or mixtures thereof. Organic peracids, such as peracetic acid, performic acid, perbenzoic acid, *m*-chloroperbenzoic acid, or perphthalic acid can also be employed. The following are examples of solvents that can be used with organic peracids: tetrahydrofuran and 60 chloroform (perbenzoic and *m*-chloroperbenzoic acid), benzene (perbenzoic acid), diethyl ether (peracetic acid). Peracetic acid can also be used without an additional solvent. Other oxidizing agents are inorganic peracids, for example, persulfuric acid, and ozone. Persulfuric acid can be used without an additional solvent. Ozone can be used in chloroform or dilute sulfuric acid. For the peracids, the oxidation reaction can be carried out at a temperature ranging from about -5 65 to about 50°C. Ambient temperature is preferred. For ozone, the reaction can be carried out at

— 78°C. The N-oxide derivative is recovered from the oxidation reaction mixture but need not be purified. The recovery of the N-oxide derivative can be accomplished using conventional techniques. For example, when 30% hydrogen peroxide-water is employed as the oxidizing agent, the N-oxide conveniently can be recovered by treating the reaction mixture with platinum 5 black or catalase (or other suitable peroxide-destroying reagent) to destroy excess hydrogen peroxide, filtering the mixture, extracting the filtrate with chloroform, separating the aqueous phase, and evaporating solvent from the aqueous phase to give the N-oxide derivative as a residue.

In Step C, the N-oxide derivative (3) formed in Step B undergoes the Cope elimination to afford 5-vinyl-2-pyrrolidinone (4). The elimination is accomplished in manner known *per se* by pyrolysis of the N-oxide derivative. Usually the pyrolysis will be carried out at a temperature of at least 140°C under reduced pressure. Suitably the temperature of the pyrolysis reaction can range from about 140 to about 185°C, preferably 150°C. Conveniently the pyrolysis can be carried out dry under reduced pressure so that the product, 5-vinyl-2-pyrrolidinone, will continuously distil from the reaction mixture. The elimination reaction may be accompanied by a deoxygenation reaction whereby N,N-dimethyl-2-[5'-oxo-2'-pyrrolidine]ethylamine is produced as a by-product. When the pyrolysis is carried out under reduced pressure, the by-product can distil from the reaction mixture along with 5-vinyl-2-pyrrolidinone. If it is desired to separate the by-product, an aqueous solution of the distillate can be treated with a sufficient amount of an acidic 15 ion exchange resin, such as Amberlite IR 120, H⁺ form, until the solution shows a neutral pH, whereby the basic by-product becomes bound to the acidic resin and is effectively removed from solution containing the desired product. The resin containing the by-product and any unreacted resin can then be separated from the solution by filtration. The neutral aqueous filtrate can be used directly in Step D or it can be further treated in manner known *per se* in order to recover 20 5-vinyl-2-pyrrolidinone. The recovery of 5-vinyl-2-pyrrolidinone can be accomplished by evaporating solvent from the neutral filtrate to give a residue, and distilling the residue under vacuum. 25 5-Vinyl-2-pyrrolidinone thus obtained can be re-dissolved in water, and the resulting solution can be subsequently used in Step D.

If desired, the resin which is removed by filtration can be treated in known manner *so as to* regenerate N,N-dimethyl-2-[5'-oxo-2'-pyrrolidine]ethylamine (2), which can then be recycled in 30 Step B.

Other methods known in the art, such as chromatography, can be used, if desired, to separate the by-product.

In Step D, 5-vinyl-2-pyrrolidinone (4) is hydrolyzed in known manner *per se* to give the 35 desired final product, 4-amino-5-hexenoic acid (5). Conditions for opening the lactam ring by acid hydrolysis are well known in the art. For example, a strong acid, such as hydrochloric acid, or trifluoroacetic acid, can be added to an aqueous solution of 5-vinyl-2-pyrrolidinone (for example, as obtained from Step C) and the resulting solution can be heated, preferably above 60°C. A most preferred hydrolysis procedure is to heat 5-vinyl-2-pyrrolidinone in 5% aqueous 40 hydrochloric acid at a temperature of 95 to 100°C.

In the acid hydrolysis performed in Step D, 4-amino-5-hexenoic acid forms an acid addition salt with the strong acid present in the reaction medium. The acid addition salt can be isolated as a residue after evaporating solvent from the reaction medium. The residue can be purified by conventional means, such as recrystallization. If desired, 4-amino-5-hexenoic acid in the form of 45 the free base or zwitterion can be obtained by contacting the acid addition salt with a strong base. The free base or zwitterion thus formed can be isolated by conventional means. For example, when the hydrolysis of 4-amino-5-hexenoic acid is carried out using 5% hydrochloric acid, the residue obtained after evaporation of solvent from the reaction medium is dissolved in ethanol/isopropanol, triethylamine is added to the resulting solution to pH 7-8, and the product 50 is separated by precipitation. The precipitate can be purified by dissolving it in water, heating the resulting solution with charcoal (90°C), filtering the mixture, and adding ethanol and isopropanol to the filtrate. Pure 4-amino-5-hexenoic acid will crystallize upon standing at 5°C.

FIGURE 2, set forth below, depicts an appropriate method for preparing 5-oxo-2-pyrrolidine-acetonitrile (1), which is the starting material employed in the process of this invention [See 55 FIGURE 1, Step A, Compound (1)].

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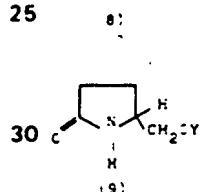
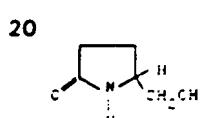
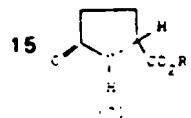
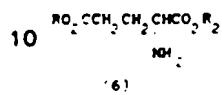
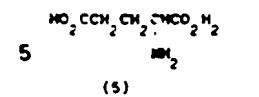
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FIGURE 2



In FIGURE 2, R is (C₁-C₆)alkyl group and -OY is *p*-toluenesulfonyloxy (tosyloxy) or methanesulfonyloxy (mesyloxy).

In Step E L- or DL-glutamic acid (5) is esterified in known manner to give the diester (6). Any conventional esterification method can be used. For example, L- or DL-glutamic acid (5) can be treated with thionyl chloride and ethanol to give diethyl glutamate.

In Step F, the diester (6) undergoes a cyclization reaction to give a pyroglutamic acid ester (7). The cyclization is accomplished in known manner by pyrolysis. The temperature of the pyrolysis can range from about 150 to 200°C. It is preferred to carry out the pyrolysis under reduced pressure so that the pyroglutamic acid ester (7) continuously distils from the reaction mixture.

In Step G, the pyroglutamic acid ester (7) is reduced to give 5-hydroxymethyl-2-pyrrolidinone (8). The reduction conditions employed must be capable of reducing the ester carbonyl without reducing the lactam carbonyl. Suitable reducing agents are lithium borohydride in tetrahydrofuran, sodium borohydride in water or ethanol, or DIBAL-H. Sodium borohydride in water or 55 ethanol is preferred.

In Step H, 5-hydroxymethyl-2-pyrrolidinone (8) is converted in known manner to the corresponding tosylxy or mesyloxy derivative (9). One method is to treat 5-hydroxymethyl-2-pyrrolidinone with tosylchloride or mesylchloride in dry pyridine. Another method for carrying out the transformation involves reacting 5-hydroxymethyl-2-pyrrolidinone with tosylchloride or mesylchloride and sodium hydroxide in methylene chloride/water in the presence of a phase transfer catalyst, such as tetra-n-butylammonium hydrogen sulfate.

In Step 1, the tosyoxy or mesyloxy derivative (9) is converted in known manner to 5-oxo-2-pyrrolidine-acetonitrile (1). The conversion can be accomplished by treating the tosyoxy or mesyloxy derivative (9) with sodium cyanide and sodium iodide in dry dimethylformamide. 5-Oxo-2-pyrrolidine-acetonitrile must be obtained free of sodium cyanide to avoid interferences.

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during Step A of the subsequent reaction sequence

Since 4-amino-5-hexenoic acid possesses a chiral center, optical isomers are possible, and 4-amino-5-hexenoic acid and the intermediates thereto shown in Fig. 1 can exist in the form of a pure enantiomer or a mixture of enantiomers, such as the racemate. As will be recognized by

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those skilled in the art, the processes of this invention can be employed to make each substantially pure individual enantiomer or the racemate of 4-amino-5-hexenoic acid, or of the intermediates thereto, depending upon the optical configuration of 5-oxo-2-pyrrolidine-acetonitrile, which is used as the starting material of the over-all process (See Step A, Fig. 1). The starting materials and the intermediates and products produced therefrom by the process

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depicted in Fig. 1 are shown below:

Starting Material (Compound 1)	Intermediates (Compounds 2, 3, and 4)	Product (Compound 5)	
15	(S)-5-oxo-2-pyrrolidine-acetonitrile	(S)-N,N-dimethyl-2-[5'-oxo-2'-pyrrolidine] ethylamine; the N-oxide thereof; and (S)-5-vinyl-2-pyrrolidinone	(S)-4-amino-5-hexenoic acid
20	(R,S)-5-oxo-2-pyrrolidine-acetonitrile	(R,S)-N,N-dimethyl-2-[5'-oxo-2'-pyrrolidine] ethylamine; the N-oxide thereof; and (S)-5-vinyl-2-pyrrolidinone	(R,S)-4-amino-5-hexenoic acid
25	(R)-5-oxo-2-pyrrolidine-acetonitrile	(R)-N,N-dimethyl-2-[5'-oxo-2'-pyrrolidine] ethylamine, the N-oxide thereof; and (S)-5-vinyl-2-pyrrolidinone	(R)-4-amino-5-hexenoic acid
30			

It has been found that the biologically active enantiomer of (4)-amino-5-hexenoic acid is the (+)-enantiomer, which is (S)-4-amino-5-hexenoic acid. Thus, the pure biologically active (S)-enantiomer or the racemate (i.e. the R,S-form) of 4-amino-5-hexenoic acid can be employed *in vivo* to inhibit GABA-T enzyme. The biologically inactive (R)-enantiomer of 4-amino-5-hexenoic acid can be converted, however, in manner known *per se* to the (R)-enantiomer of 4-amino-5-hydroxy acid. The method for preparing (R)-4-aminohex-5-yoic acid from (R)-4-amino-5-hydroxy acid is illustrated in Examples 10 to 13. The conversion of 5-vinyl-2-pyrrolidinone to 4-aminohex-5-yoic acid via 5-ethynyl-2-pyrrolidinone is also described in U.S. Patent No.

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4,178,463

The biochemical and pharmacological effects of 4-aminohex-5-yoic acid are described in Jung et al., *Biochem. and Biophys. Res. Comm.*, 67, 301 (1975); Jung et al., *J. Neurochemistry*, 28, 717 (1977); Jung et al., *Biochemistry*, 17, 2628 (1978); Boucher et al., *Eur. J. Biochem.*, 98, 363 (1979); *Biochem. Pharmacology*, 28, 1705 (1979); and Lippert et al., *Brain Research Bull.*, 5, 375 (1980). It has been reported by Lippert et al., *supra* and Boucher et al., *supra*, that the (+)-enantiomer of 4-aminohex-5-yoic acid, which is (S)-4-aminohex-5-yoic acid, is the only enantiomer of 4-aminohex-5-yoic acid which will irreversibly inhibit GABA-T. More recent experiments have demonstrated, however, that the (R)-enantiomer is an irreversible inhibitor of GABA-T both *in vivo* and *in vitro*. For example, (R)-aminohex-5-yoic acid gave the following effects on GABA-T activity and GABA concentrations in mice brain using the test method of Jung et al., *J. Neurochemistry*, *supra*:

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Dose (mg/kg)	% Inhibition of GABA-T (a)	GABA Concentration % Control (a)	
control	0	100	55
25	31	103	
60 50	50	125	60
100	66	180	
200	81	275	

(a) 4 hours after injection of the test compound, i.p.

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- In a chronic experiment, a group of five rats was given oral daily doses of 100 mg/kg of (R)-4-aminohex-5-yonic acid. A separate group of animals was used as control. Twenty-four hours after the last dose, the animals were sacrificed and the cortex was dissected from the rest of the brain. GABA-T activity was measured in homogenates of brain minus the cortex and was found to be decreased by 81% in the animals treated with (R)-4-aminohex-5-yonic acid as compared to controls. GABA concentration was measured in homogenates of the cortex and was found to be approximately doubled in the animals treated with (R)-4-aminohex-5-yonic acid. During the first week of treatment, the animals lost body weight and lost hair on their backs. These effects appeared to disappear during the second week, however. 5
- At dosages of 100 and 200 mg/kg, administered i.p., (R)-4-aminohex-5-yonic acid was shown to protect mice against convulsions and death, induced by mercaptoacrylic acid, administered at a dose of 53 mg/kg, i.p., 6 hours after injection of (R)-4-aminohex-5-yonic acid. However, no protection against running fits was afforded. 10
- At a single dose of 400 mg/kg, i.p., in mice, (R)-4-aminohex-5-yonic acid produced sedation within 3C minutes, but 24 hours later the animals were dead. 15
- (S)-5-Oxo-2-pyrrolidine-acetonitrile [Compound (1)] and its preparation from L-glutamic acid via (S)-5-tosyloxymethyl-2-pyrrolidinone by the reaction sequence shown in Fig. 2 (Steps E, F, G, H, and I) are described by Hardegger and Ott, *Helv. Chim. Acta*, 38, 318 (1955). The reduction of ethyl-(S)-pyroglutamate with sodium borohydride in ethanol is described by Saito et al, *Chem. Pharm. Bull.*, 28, 1449 (1980). The reduction of ethyl-(S)-pyroglutamate with lithium borohydride is described by Bruckner et al, *Acta Chim. Hung.*, 21, 105, 116 (1959). The preparation of ethyl-(S)-pyroglutamate from diethyl L-glutamate is described by Fischer and Boehmer, *Chem. Ber.*, 44, 1333 (1911) and Abderhalden and Wield, *Hoppe-Seyler's Z. Physiol. Chem.*, 74, 459 (1911). 20
- In its composition-of-matter aspects, the present invention comprehends N,N-dimethyl-2-[5'-oxo-2'-pyrrolidine]ethylamine or the N-oxide thereof, or an acid addition salt thereof. 25
- The following Examples will illustrate processes for carrying out the invention. As employed in the Examples, "THF" means tetrahydrofuran and "DMF" means dimethylformamide. Drying of organic extracts was accomplished using anhydrous sodium sulfate. 30
- Example 1**
Ethyl L-pyroglutamate
- Thionyl chloride (217 ml) is slowly added to a stirred suspension of L-glutamic acid (417 g) in dry ethanol (1 L), and the mixture is refluxed for 5 hours. Ethanol is removed under vacuum to give a residue, which is dissolved in water (500 ml). The water solution is made alkaline with saturated sodium carbonate solution and extracted with chloroform (4 x 200 ml). The chloroform extract is dried (Na_2SO_4) and evaporated to give crude product (178 g). This material is heated (160°C) under vacuum (10 mm Hg) for 3 hours. Subsequent distillation gives pure ethyl L-pyroglutamate (126.6 g; b.p. 126°C/0.07 mm Hg, $[\alpha]_D = -2.15^\circ \pm 0.01$ (H₂O, c = 17.8)). 35
- Example 2**
(S)-5-Hydroxymethyl-2-pyrrolidinone
- Under an atmosphere of nitrogen, ethyl L-pyroglutamate (31.4 g), obtained as in Example 1, dissolved in THF (100 ml), is added slowly to a stirred suspension of lithium borohydride (8 g) in dry THF (260 ml). During the addition, the temperature is kept below 40°C. The mixture is then stirred at room temperature for 48 hours. Water (50 ml) and THF (150 ml) is added, and the resulting mixture is stirred overnight. Filtration (methanol washing) and evaporation of solvent gives a residue which is digested with methanol (100 ml). The mixture is filtered (chloroform washing, 100 ml), evaporated and dissolved in chloroform again. Filtration and evaporation give the title compound as an oil: 24.2 g. 40
- Example 3**
(S)-5-[Methanesulfonyloxy]-methyl-2-pyrrolidinone
- Crude (S)-5-hydroxymethyl-2-pyrrolidinone (13 g), obtained as in Example 2, dissolved in dry pyridine (120 ml), and cooled with ice, is treated with mesylchloride (10 ml), keeping the temperature below 5°C. The mixture is allowed to warm to room temperature and is stirred for 1 more hour. Water (2 ml) is added, and the mixture is stirred for 10 more minutes. The solvent is removed under vacuum, and the residue obtained is digested with dichloromethane. The mixture is filtered (methylene chloride-washing) and solvent is removed by evaporation to give a residue. The residue is dissolved in water (100 ml) and the resulting solution is treated with a cation exchange resin (H⁺-form, 2 g) and an anion exchanger (OH⁻-form, 2 g). Filtration and evaporation give an oil which is dissolved in chloroform. After removal of insoluble material, drying and evaporation give crude title compound, 16.8 g. This material is recrystallized from cold methanol to yield 12.12 g. 45
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Example 4**(S)-5-Oxo-2-pyrrolidine-acetonitrile**

A mixture of (S)-5-[methanesulfonyloxy]methyl-2-pyrrolidinone (19.3 g), obtained as in Example 3, sodium cyanide (7.3 g), sodium iodide (50 mg), and dry DMF (100 ml) is stirred and heated at 90°C for 3 hours. Stirring is continued at room temperature overnight. Salts are then removed by filtration (dichloromethane washing). The residue obtained on evaporation is dissolved in dichloromethane (50 ml). insoluble material is filtered off, and the filtrate is evaporated again. Ethyl acetate (5 ml) is added. Crude title compound (11.4 g) crystallizes upon standing overnight (5°C). Recrystallization from ethyl acetate/diethyl ether gives the pure title compound (9.2 g).

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Example 5**(S)-N,N-Dimethyl-2-[5'-oxo-2'-pyrrolidine]-ethylamine**

To a solution of (S)-5-oxo-2-pyrrolidine-acetonitrile (9.42 g, 80 mmole), obtained as in Example 4, in ethanol (80 ml), a 33% solution of dimethylamine in ethanol (28 ml) is added, and the resulting mixture is hydrogenated overnight (30 p.s.i.) in the presence of palladium-on-barium sulfate (5%, 12 g). Distillation gives the title compound (8.63 g), b.p. 105–110°C/0.15 mm Hg.

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Example 6**(S)-5-Vinyl-2-pyrrolidinone**

(S)-N,N-Dimethyl-2-[5'-oxo-2'-pyrrolidine]ethylamine (3.69 g), obtained as in Example 5, dissolved in water (10 ml), is treated with 30% hydrogen peroxide (2.66 g). After 2 hours, more hydrogen peroxide (2.66 g) is added, and stirring is continued for 80 hours. A third portion of 30% hydrogen peroxide (2.65 g) is then added, and stirring is continued for another 24 hours to complete the oxidation (pH neutral). The excess of hydrogen peroxide is destroyed by stirring (12–24 hours) with a few mg of catalase; absence of hydrogen peroxide is tested for with "Merkoquan" peroxide test paper. The mixture is filtered and evaporated to give the crude N-oxide (presumably as a hydrate) as an oil (4.7 g). This oil is heated under vacuum (0.1 mm Hg). At 130°C, the material solidifies, and at 160°C (bath temperature), the title compound distills (2.3 g). According to MS analysis, the crude product contains <40% of (S)-N,N-dimethyl-2-[5'-oxo-2'-pyrrolidine]ethylamine.

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Example 7**(S)-4-Amino-5'-hexenoic acid**

Crude (S)-5-vinyl-2-pyrrolidinone (1.97 g), obtained as in Example 6, is heated with 5% aqueous H₂O₂chloric acid (50 ml) at 95°C for 5 hours. After evaporation of solvent, the resulting residue is dissolved in a mixture of ethanol (5 ml) and isopropanol (12 ml). Upon addition of triethylamine until pH 7–8, the crude title compound precipitates (1.0 g). This material is dissolved in water (2 ml). Treatment with charcoal (90°C, 30 minutes), and addition of ethanol (10 ml) and isopropanol (2 ml) give pure title compound which crystallizes on standing at 5°C overnight. Addition of more isopropanol gives a second crop; total: 450 mg. [α]_D = 12.4 ± 0.6 (H₂O, c = 0.515). 6C (opt. active column + MS): optical purity at best 99% (no R-isomer detectable).

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Example 8**(S)-5-Vinyl-2-pyrrolidinone**

The oxidation of (S)-N,N-dimethyl-2-[5'-oxo-2'-pyrrolidine]ethylamine is repeated according to the procedure of Example 6. Excess of hydrogen peroxide is destroyed with platinum black. The mixture is filtered and the filtrate is extracted with chloroform. The aqueous phase is evaporated to give a residue. This is dissolved in a few ml of ethanol. Evaporation of solvent gives the N-oxide (presumably as the hydrate) as a white solid. Recrystallization from ethanol gives 7.1 g of material (starting from 8.63 g of the amine starting material). On dry distillation, (S)-5-vinyl-2-pyrrolidinone distils at 150°C (0.1 mm Hg) bath temperature. The temperature is raised finally to 185°C. According to NMR analysis, the slightly yellow coloured distillate (4.07 g) contains about 25 mole-% of (S)-N,N-dimethyl-2-[5'-oxo-2'-pyrrolidine]ethylamine. The distillate is dissolved in water (80 ml), and the resulting solution is treated with an ion exchange resin (Amberlite R 150, H⁺-form) until neutral (10 ml of wet resin). Filtration, evaporation, and distillation (b.p. 130°C/0.1 mm Hg) give (S)-5-vinyl-2-pyrrolidinone as a colourless liquid (2.488 g, hydroscopic, purity ≥98% (GC/MS)). The resin is collected and treated with 6N HCl (2 × 50 ml) and washed with water (50 ml). Evaporation of solvent gives (S)-N,N-dimethyl-2-[5'-oxo-2'-pyrrolidine]ethylamine (as the hydrochloride) as a solid (1.47 g).

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Example 9**(S)-5-Tosyloxymethyl-2-pyrrolidinone**

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Ethyl (L)-pyroglutamate (15.7 g., dissolved in water (50 ml) is added slowly at 0°C to a solution of sodium borohydride (2.2 g.) in water (50 ml). The mixture is allowed to warm up over a one-hour period after which it is stirred at room temperature for 20 minutes. Acetone (5 ml) is added and the stirring is continued for 30 minutes. Solvent is evaporated to give a dry residue which is dissolved in water (100 ml). The solution is then concentrated to a volume of 40 ml. To the concentrated solution are added: caustic soda (5 g.), tosyl chloride (18.10 g.) in dichloromethane (100 ml), and tetra-n-butyl ammonium hydrogen sulfate (1.03 g.). The resulting mixture is stirred vigorously for 42 hours at room temperature. The organic layer is separated, and the aqueous layer is extracted with dichloromethane (50 ml). The organic layers are combined and dried. Evaporation of solvent gives a residue which is recrystallized from toluene (150 ml) to give 13.6 g. of pure (S)-5-tosyloxymethyl-2-pyrrolidinone. $[\alpha]_D^0 = +7.80 \pm 0.04$ ($c = 2.64$, EtOH)

Example 10

- 15 **(R)-5-Vinyl-2-pyrrolidinone**
 To a stirred suspension of (R)-4-amino-5-hexenoic acid (2.58 g., 20 mmoles) in methanol (20 ml), thionyl chloride (1.5 ml) is added dropwise with ice cooling. After refluxing for 3.5 hours, evaporation of solvent gives an oil which is dissolved in water (~15 ml). Sodium carbonate (4 g.) is added, and the resulting mixture is extracted 3 times with dichloromethane. Drying and evaporation gives the methyl ester as an oil (2.85 g.).
 NMR (CDCl₃) δ 1.35 (2H, s(NH₂)); 1.62-2.03 (2H, m); 2.17-2.58 (2H, m); 3.32 (1H, q, J = 7 Hz); 3.67 (3H, s); 4.87-6.10 (3H, m).
 The oil is heated in toluene (bath temperature, 120°C) for 40 hours. Distillation in a Kugelrohr (0.1 mm Hg, 140°C) gives the title compound as a colorless oil (1.57 g.). $[\alpha]_D^0$ (EtOH, c = 4) -54.84° ± 0.08°.
 NMR (CDCl₃) δ 1.47-2.53 (4H, m); 4.13 (1H, broadened q, J = 7 Hz); 4.93-6.13 (3H, m); 7.53 (1H, broad s).

- 30 **(R)-5-(1',2'-dibromoethyl)-2-pyrrolidinone**
 To a solution of (R)-5-vinyl-2-pyrrolidinone (1.28 g., 11.5 mmoles) obtained as in Example 10, in carbon tetrachloride (18 ml) is added a solution of bromine (0.67 ml) in carbon tetrachloride (5 ml) dropwise with ice cooling and stirring. During this addition, a viscous oil separates. After the addition, stirring is continued for 1 hour at room temperature. The solvent is removed under vacuum, and the residue obtained is dissolved in dichloromethane and washed with 10% sodium bisulfite solution until nearly colorless. The aqueous phase is made basic with (solid) sodium carbonate and extracted twice with dichloromethane. The combined organic phases are dried and evaporated to give an oil which is purified by flash chromatography on silica gel (200 g, eluent: hexane/ethyl acetate/chloroform/methanol 3.2:2.1, Rf (same solvent): 0.33). The pure title compound crystallizes on evaporation and is obtained as a white solid (1.54 g.).
 NMR (CDCl₃): δ 1.6-2.75 (4H, m); 3.5-3.93 and 3.93-4.53 (4H, 2m); 7.63 (1H, broad s).

- 35 **Example 12**
(R)-5-Ethynyl-2-pyrrolidinone
 45 To a suspension of potassium-tert-butoxide (3.57 g.) in dry THF (10 ml), cooled at -65°C, a solution of (R)-5-(1',2'-dibromoethyl)-2-pyrrolidinone (1.44 g., 5.31 mmoles) obtained as in Example 11, in THF (20 ml) is added slowly, whereby the internal temperature is kept between -60°C and -65°C. The mixture is allowed to warm up to -20°C; then it is poured into a vigorously stirred ice-cold solution of acetic acid (2.5 g.) in water (10 ml). The mixture is diluted with ether (50 ml). The aqueous layer is separated, made basic with sodium carbonate, and extracted twice with dichloromethane. The combined organic phases are dried and evaporated to give an oil which still contains acetic acid. It is dissolved in water (~20 ml), and solid sodium carbonate is added until basic. Three extractions with dichloromethane, drying and evaporation give an oil (0.82 g.) which is purified by chromatography on silica (100 g; eluent: hexane/ethyl acetate/chloroform/methanol 3:2:2:1; Rf (same solvent): 0.23). Pure title compound is obtained as a white solid (0.33 g.); $[\alpha]_D^0$ (EtOH, c = 3.1): +15.82° ± 0.06°.
 NMR (CDCl₃): δ 1.92-2.73 (5H, m); 4.40 (1H, m); 7.95 (1H, broad s).

- 40 **Example 13**
(R)-4-Aminohex-5-yonic acid
 45 (R)-5-Ethynyl-2-pyrrolidinone, obtained as in Example 13, is treated with 2N hydrochloric acid at 100°C for 6 hours. Solvent is removed by evaporation and a crude product is obtained. The crude amino acid product is converted to the methyl ester, N-trifluoroacetyl derivative, and the derivative is analyzed by GC ("chiravil"), which indicated an optical purity of 100%, with no S-enantiomer detectable.

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CLAIMS

- 1 A process for preparing 5-vinyl-2-pyrrolidinone which comprises the pyrolysis of the N-oxide of N,N-dimethyl-2-[5'-oxo-2'-pyrrolidine]ethylamine.
- 5 2 A process as claimed in Claim 1 wherein the pyrolysis is carried out at a temperature of at least 140°C under reduced pressure. 5
- 3 A process as claimed in Claim 2 wherein the temperature is in the range of 140 to 185°C.
- 4 A process as claimed in Claim 3 wherein the temperature is about 150°C.
- 10 5 A process as claimed in any one of Claims 1 to 4 wherein an aqueous solution of the pyrolysis distillate is contacted with an ion exchange resin to remove N,N-dimethyl-2-[5'-oxo-2'-pyrrolidine]ethylamine by product and the resin is separated from the treated aqueous solution.
- 15 6 A process as claimed in any one of Claims 1 to 5 wherein the N-oxide of N,N-dimethyl-2-[5'-oxo-2'-pyrrolidine]ethylamine is in the form of the (S)-enantiomer.
- 7 A process as claimed in Claim 1 and substantially as hereinbefore described in Example 6 or 8. 15
- 8 5-Vinyl-2-pyrrolidinone whenever prepared by a process as claimed in any one of Claims 1 to 7.
- 9 5-Vinyl-2-pyrrolidine as claimed in Claim 8 in the form of the (S)-enantiomer.
- 20 10. N,N-Dimethyl-2-[5'-oxo-2'-pyrrolidine]ethylamine, or the N-oxide thereof, or an acid addition salt thereof. 20
- 11 N,N-Dimethyl-2-[5'-oxo-2'-pyrrolidine]ethylamine, or the N-oxide thereof, or an acid addition salt thereof, as claimed in Claim 10 in the form of the (S)-enantiomer.
- 12 A process for preparing N,N-dimethyl-2-[5'-oxo-2'-pyrrolidine]ethylamine, or the N-oxide thereof, which comprises reacting 5-oxo-2-pyrrolidine-acetonitrile with hydrogen and dimethylamine in the presence of a palladium catalyst and, when the N-oxide is required, oxidizing the N,N-dimethyl-2-[5'-oxo-2'-pyrrolidine]-ethylamine product of said reaction. 25
- 13 A process as claimed in Claim 12 wherein the reaction with hydrogen and dimethylamine is carried out in a (C₁-C₆)alkanol and/or water at a temperature of 20 to 100°C and a hydrogen gas pressure of 1 to 20 atmospheres and the catalyst is palladium-on-barium sulfate. 30
- 14 A process as claimed in Claim 13 wherein the temperature is ambient temperature and the hydrogen gas pressure is 2 atmospheres.
- 15 A process as claimed in any one of Claims 12 to 14 wherein the N,N-dimethyl-2-[5'-oxo-2'-pyrrolidine]-ethylamine product is oxidized to the N-oxide thereof.
- 35 16. A process as claimed in Claim 15 wherein the oxidation is carried out with hydrogen peroxide in water and/or a (C₁-C₆)alkanol. 35
- 17 A process as claimed in any one of Claims 12 to 16 wherein the 5-oxo-2-pyrrolidine-acetonitrile is in the form of the (S)-enantiomer thereof.
- 18 A process as claimed in Claim 12 and substantially as hereinbefore described in Example 5. 40
19. N,N-Dimethyl-2-[5'-oxo-2'-pyrrolidine]ethylamine, or the N-oxide thereof, whenever prepared by a process as claimed in any one of Claims 12 to 18.
- 20 N,N-Dimethyl-2-[5'-oxo-2'-pyrrolidine]ethylamine, or the N-oxide thereof, as claimed in Claim 19 in the form of the (S)-enantiomer. 45
- 21 A process for preparing 5-vinyl-2-pyrrolidinone which comprises:
- (a) reacting 5-oxo-2-pyrrolidine-acetonitrile with hydrogen and dimethylamine in the presence of a palladium catalyst to form N,N-dimethyl-2-[5'-oxo-2'-pyrrolidine]ethylamine.
- (b) oxidizing N,N-dimethyl-2-[5'-oxo-2'-pyrrolidine]-ethylamine to produce the corresponding N-oxide derivative; 50
- (c) dry pyrolysis of the N-oxide derivative to form 5-vinyl-2-pyrrolidinone, and, optionally,
- (d) separating N,N-dimethyl-2-[5'-oxo-2'-pyrrolidine]-ethylamine by-product from 5-vinyl-2-pyrrolidinone.
- 22 A process as claimed in Claim 21 wherein the reaction with hydrogen and dimethylamine in Step (a) is carried out in a (C₁-C₆)alkanol and/or water at a temperature of 20 to 100°C and a hydrogen gas pressure of 1 to 20 atmospheres and the catalyst is palladium-on-barium sulfate. 55
- 23 A process as claimed in Claim 22 wherein the temperature is ambient temperature and the hydrogen gas pressure is 2 atmospheres.
- 24 A process as claimed in any one of Claims 21 to 23 wherein the oxidation in Step (b) is carried out with hydrogen peroxide in water and/or a (C₁-C₆)alkanol. 60
- 25 A process as claimed in any one of Claims 21 to 24 wherein the pyrolysis in Step (c) is carried out at a temperature of at least 140°C under reduced pressure.
- 26 A process as claimed in Claim 25 wherein the pyrolysis temperature is in the range 140 to 185°C.
- 27 A process as claimed in Claim 26 wherein the pyrolysis temperature is about 150°C. 65

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28. A process as claimed in any one of Claims 21 to 27 wherein the N,N-dimethyl-2-[2'-
oxo-5'-pyrrolidine]-ethylamine by-product is separated in Step (d) from 5-vinyl-2-pyrrolidinone by
contacting an aqueous solution of the pyrolysis distillate with an acidic ion exchange resin and
separating the resin from the treated aqueous solution. 5
- 5 29. A process as claimed in any one of Claims 21 to 23 wherein the 5-oxo-pyrrolidine-
acetonitrile is in the form of the (S)-enantiomer.
30. 5-Vinyl-2-pyrrolidinone whenever prepared by a process as claimed in any one of Claims
21 to 29.
31. 5-Vinyl-2-pyrrolidinone as claimed in Claim 30 in the form of the (S)-enantiomer. 10
- 10 32. A process for preparing 4-amino-5-hexenoic acid which comprises preparing 5-vinyl-2-
pyrrolidinone according to a process as claimed in any one of Claims 1 to 7 and 21 to 29 and
then hydrolyzing the 5-vinyl-2-pyrrolidinone product.
33. A process as claimed in Claim 32 wherein the hydrolysis of 5-vinyl-2-pyrrolidinone is
carried out using a strong acid at 60 to 100°C. 15
- 15 34. A process as claimed in Claim 33 wherein the strong acid is aqueous hydrochloric acid.
35. A process as claimed in any one of Claims 32 to 34 wherein the 5-vinyl-2-pyrrolidinone
is in the form of the (S)-enantiomer.
36. 4-Amino-5-hexenoic acid whenever prepared by a process as claimed in any one of
Claims 32 to 35. 20
- 20 37. 4-Amino-5-hexenoic acid as claimed in Claim 36 in the form of the (S)-enantiomer.
38. A process as claimed in Claim 22 and substantially as hereinbefore described.
39. A process as claimed in Claim 32 and substantially as hereinbefore described.

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